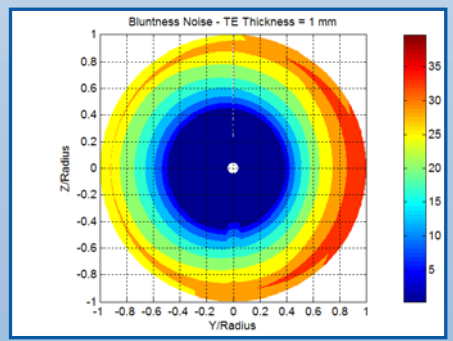
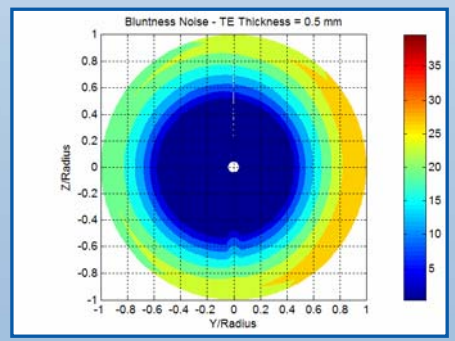
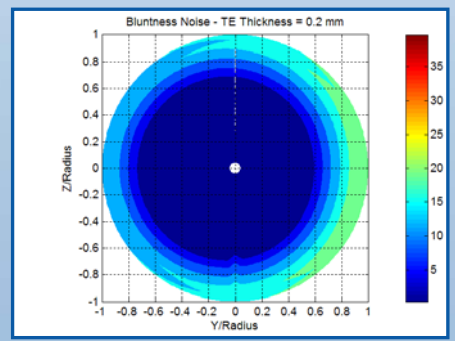
Aeroacoustics Supporting Research & Testing

DOE Wind Program Implementation Meeting
16-18 November 2004

Paul Migliore and Pat Moriarty







Presentation Topics

- *What are the issues?*
- *How are we addressing those issues?*
  - *i.e. what are the elements of our research program*
- *Recent accomplishments*
- *Outreach and industry participation*
- *Research and testing plans for the future*

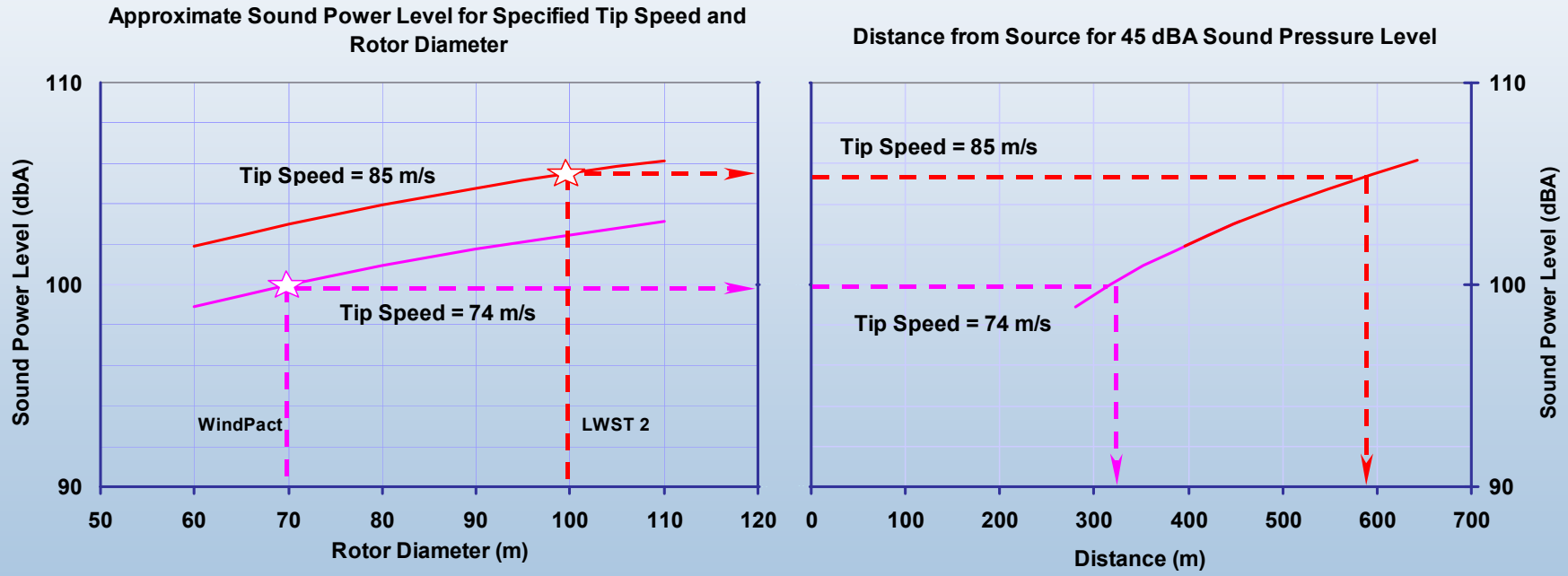
**Reports and conference pre-prints available at www.nrel.gov/publications/*

What are the issues?

- ***Objectionable noise is an impediment to deployment.***
  - *Complaints by residents threaten permitting.*
  - *Projects must comply with established community noise standards (40 – 45 dBA is typical).*
- ***Noise mitigation tools will enable more slender blades and higher tip speeds.***
  - *15% increase in tip speed yields 5-7% COE reduction.*

    (Source: WindPact studies and LWST Phase I proposals)
  - *But 15% increase in tip speed = 3 dBA increase in sound emission.*

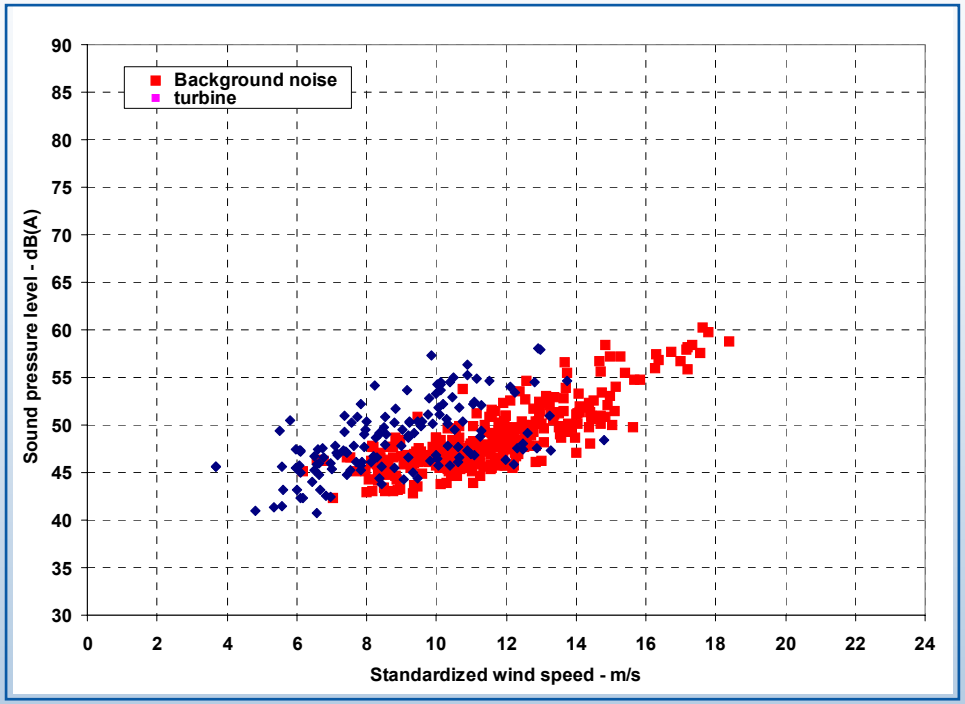
Increased tip speeds require turbines to be placed further from residents to achieve acceptable noise levels.



The research approach to address the issues

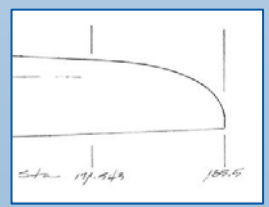
- ***Obtain field test data for wind turbine acoustic emissions to:***
  - *Evaluate progress in subsequent generations of wind turbines.*
  - *Provide a target for improving new designs.*
  - *Inform the public of what to expect.*
- ***From wind tunnel tests, develop a database of airfoil aeroacoustic and aerodynamic data to:***
  - *Facilitate intelligent trade offs between noise and performance.*
- ***Understand and control sound emissions – develop design and analysis tools.***
  - *Semi-empirical methods – near term (2004-2005)*
  - *Physics-based (CFD/CAA)– longer term (2006-2007)*
- ***Develop "quiet" planform and blade-tip shapes.***

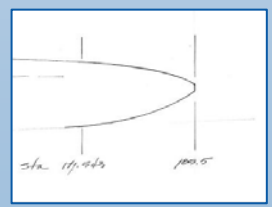
Field Tests of Small Wind Turbines

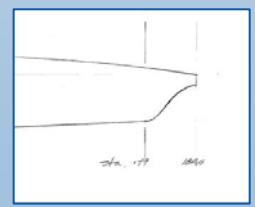


Bergey XL.1 is "state-of-the art" for small wind turbines tested.

Low noise blade tips are being investigated in field tests.

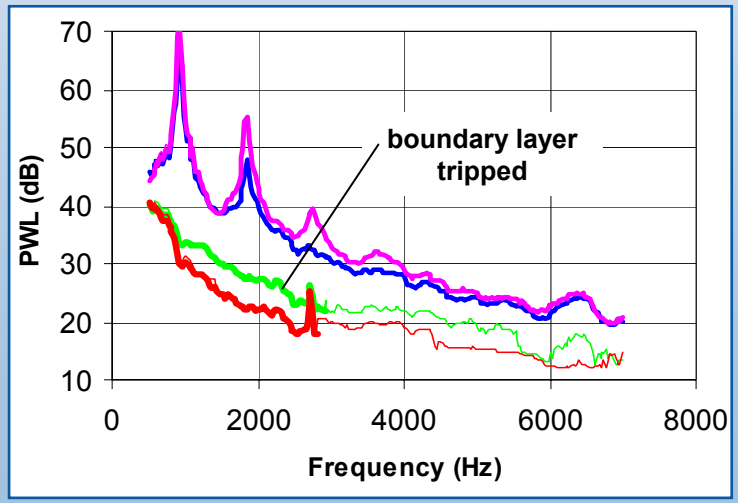


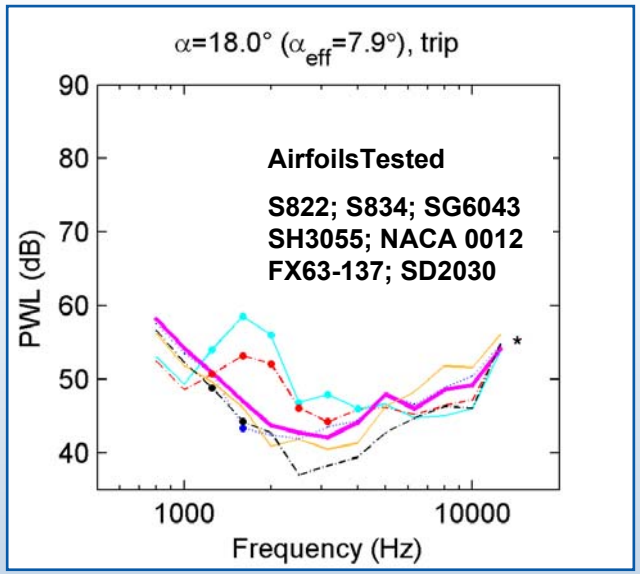




Wind Tunnel Aeroacoustic Tests (SWT Airfoils)

- *All clean airfoils exhibited pure tones at low Re. Tripping the boundary layer eliminated tones and decreased broadband noise.*
- *Extensive database published for industry benefit.*

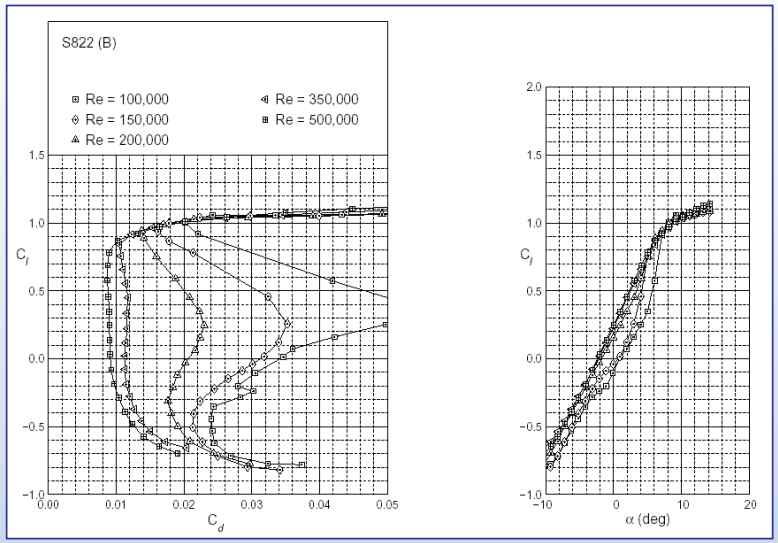




- *Some airfoils are definitely quieter than others.*
- *Trailing edge noise dominates, except in the presence of extreme turbulence. Thin leading edges are noisiest.*

Wind Tunnel Aerodynamic Tests (SWT Airfoils)

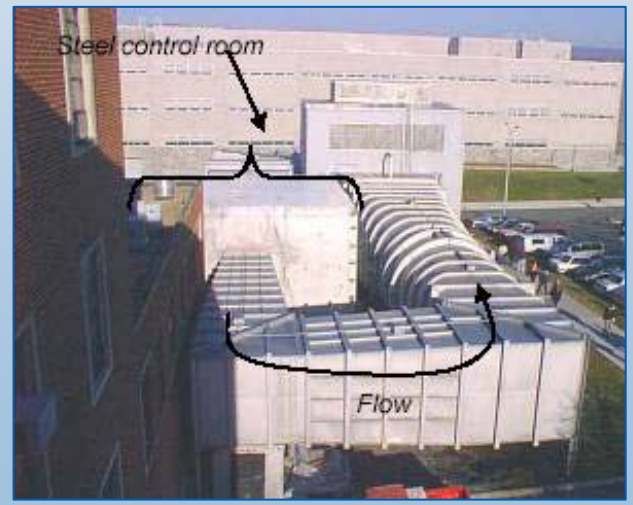
- *Aerodynamic (and aeroacoustic) database established for six airfoils at Re =500,000 and less.*
- *Five DOE / NREL DWT grantees or subcontractors are using data for new designs.*



- *Erratic behavior at low Re was characterized.*
- *Data suggest it may be prudent to design new SWT rotors with tripped data.*

Wind Tunnel Aeroacoustic Tests (LWST Airfoils)

- ***Goal: available, affordable, high-Re wind tunnel aeroacoustic (and aerodynamic) test capability in the U.S.***
- ***Objective: obtain airfoil database for shapes that are candidates for large LWST rotors.***
- ***VPI wind tunnel is an excellent baseline facility.***
  - *6 ft. test section; 260 fps speed (Re = 5 x 10^{6}) and low turbulence (0.05%)*
  - *Unsteady, turbulent inflow capability*
  - *Open or closed jet*
  - *Low cost*

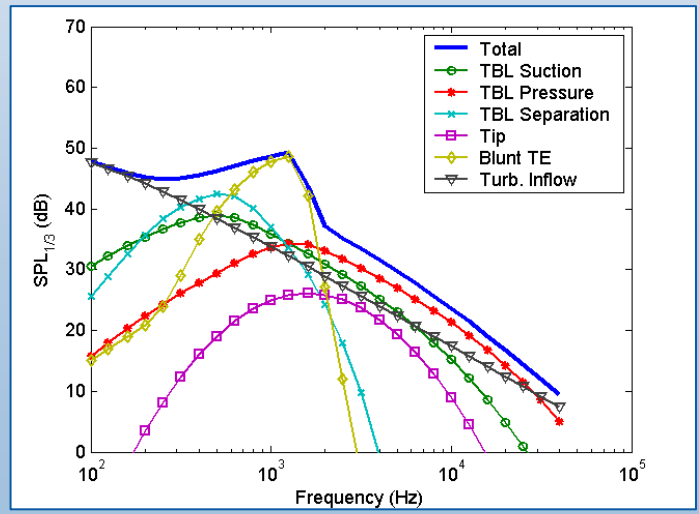


Wind Tunnel Aeroacoustic Tests (LWST Airfoils)

- ***Phase I (through Feb 2005) – facility upgrade and demonstration***
  - *Kevlar-walled test section*
  - *64-microphone phased array measurement system*
  - *Background noise and benchmark NACA 0012 tests*
- ***Phase II (through Feb 2006) – full anechoic chamber construction; calibration of test section and instrumentation***
  - *Completely enclose test section in anechoic chamber.*
  - *Develop 128-microphone phased array.*
- ***Phase III (Feb 2006) – conduct archival aeroacoustic and aerodynamic tests***
  - *NACA 0012, S817, S826, S830, Delft DU-96, Riso-B1-18*

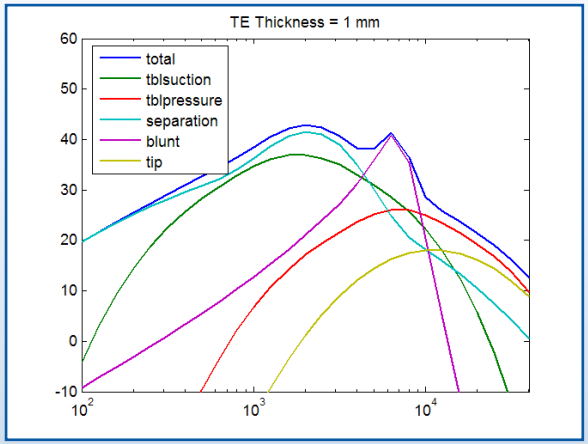
Semi-Empirical Code Development

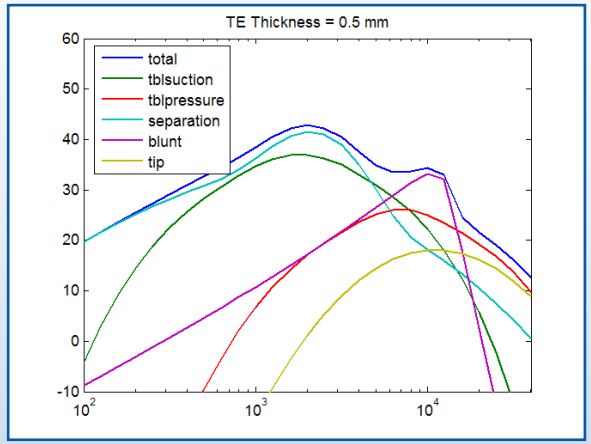
- ***NASA (Brooks, et al) method adapted to wind turbines – incorporated in FAST (2003).***
- ***Validation studies showed mixed results: general trends and levels were reasonable, but improvements needed.***
  - *New inflow turbulence method (Guidati) installed in 2004.*
  - *XFOIL installed in 2004 for direct t.e. boundary layer calculations. RFOIL upgrade planned in 2005.*
  - *New t.e. noise upgrade (Parchen) planned in 2005.*
  - *Validation studies based on CART and SWRT field tests to follow.*

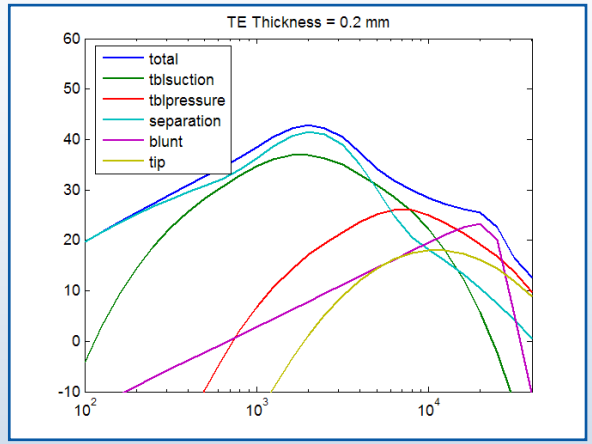


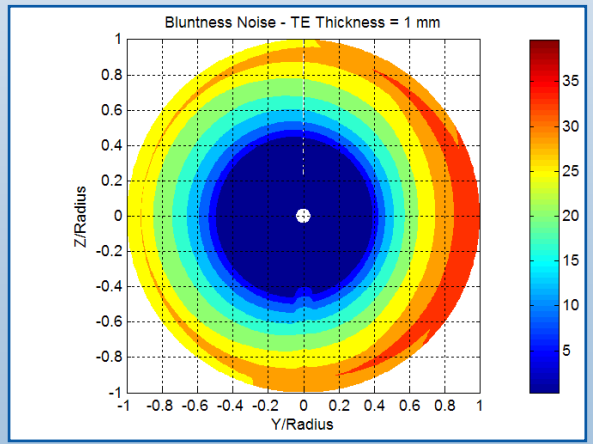
Example Use of Semi-Empirical Code

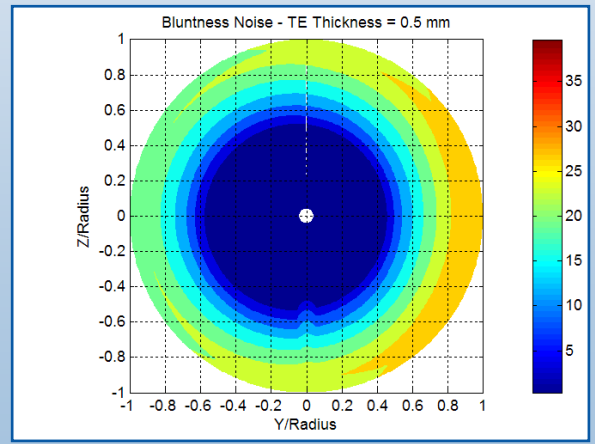
(Trailing Edge Bluntness Noise)

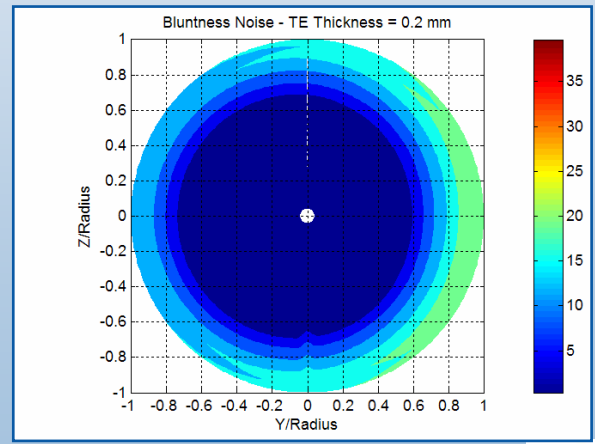






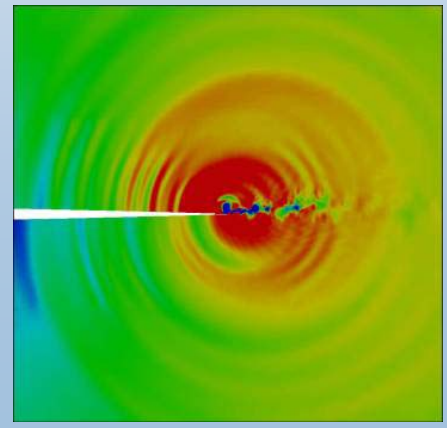






Computational Aeroacoustics

- *Goal: develop a physics based approach to modeling wind turbine aeroacoustics.*
- *Objective: obtain a suite of codes installed on NREL / industry computers.*
- *15 proposals received, including some "world class" research teams.*
- *Penn State / Florida State selected to proceed.*



Computational Aeroacoustics

- ***Phase I (Feb 2004)***
  - *Review of previous research*
  - *Formulation of computational approach*
  - *NASA Langley and Glenn scientists on review panel.*
- ***Phase II (through Feb 2006)***
  - *Rotating blades, separated flows, trailing edge noise, blade tip noise, radiation, propagation included.*
  - *Conduct validation studies.*
  - *Develop user friendly interface.*
  - *Installation at NREL and training will be provided.*

Outreach and Industry Participation

- ***SWT Field Tests***
  - *Responded to industry need for independent testing/reporting.*
  - *Test data establishes "state of the art."*
- ***SWT Airfoil Wind Tunnel Tests***
  - *Data directly affect industry designs.*
  - *DWT designers currently using data: Bergey, SWWP, Windward, ARE, KWI.*
- ***Semi-Empirical Prediction Method***
  - *Part of FAST, a U.S.wind industry standard*
  - *GE Wind – 1.5 MW validation study and future LWST efforts*
  - *Clipper Windpower – for modeling of 2.5 MW LWST*
  - *Southwest Windpower – used in design studies of Storm turbine*

Outreach and Industry Participation

- ***LWST Airfoil Wind Tunnel Tests***
  - *We are on track to establish world class U.S. facility.*
    - *An alternate to NASA LTPT, Delft, Stuttgart, DNW tunnels*
    - *Costs will be a fraction of NASA LTPT, DNW, Sverdrup tunnels*
    - *Expect most comprehensive airfoil aeroacoustic database ever.*
  - *We have close cooperation with NASA Langley Research Center, with assistance in test planning and instrumentation.*
  - *GE Wind, Clipper Windpower, Riso CEC/UCD will participate in tests.*
  - *Significant cost contributions by DOD, NASA, VPI*

Outreach and Industry Participation

- ***Computational Aeroacoustics***
  - *Industry partners are keenly interested in pursuing CFD/CAA.*
  - *NASA Langley and NASA Glenn scientists have offered ongoing expert assistance.*
  - *Georgia Tech, NAU, UCD, GE Wind, GEC, PSU, FSU, NASA are potential user specialists to be consulted.*

View of the Future: 2005-2006

- ***Semi-empirical prediction method***
  - *Add airfoil shape recognition.*
  - *Improve the leading-edge inflow turbulence noise module.*
  - *Improve the trailing-edge turbulent boundary layer noise module.*
  - *Conduct validation studies in cooperation with industry partners.*
- ***VPI facility will be available for large LWST airfoil tests.***
- ***Wind tunnel test data for LWST airfoils will be published.***

View of the Future: 2006-2007

- ***CFD/CAA code development/validation completed.***
- ***CFD/CAA code training program completed at NREL.***
- ***CFD/CAA code on NREL web site and in-use by researchers.***